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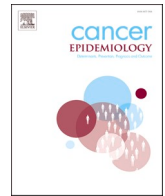
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## Area-level deprivation and oral cancer in England 2012–2016

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### ABSTRACT

**Background:** The relationship between deprivation and oral cancer is complex. We examined magnitude and shape of deprivation-related inequalities in oral cancer in England 2012–2016.

**Methods:** Oral cancer was indicated by cancers of the lip and oral cavity (ICD10 C00–C06) and lip, oral cavity and pharynx (C00–C14) and deprivation by the Index of Multiple Deprivation. Deprivation inequality in incidence and mortality rates of oral cancer outcomes was measured using the Relative Index of Inequality (RII). Fractional polynomial regression was used to explore the shape of the relationships between deprivation and oral cancer outcomes. Multivariate regression models were fitted with the appropriate functions to examine the independent effect of deprivation on cancer adjusting for smoking, alcohol and ethnicity.

**Results:** Incidence rate ratios (IRRs) and mortality rate ratios (MRRs) were greater for more deprived areas. The RII values indicated significant inequalities for oral cancer outcomes but the magnitude of inequalities were greater for mortality. The relationships between deprivation and oral cancer outcomes were curvilinear. Deprivation, Asian ethnicity and alcohol consumption were associated with higher incidence and mortality rates of oral cancer.

**Conclusion:** This is the first study, to our knowledge, exploring the shape of socioeconomic inequalities in oral cancer at neighbourhood level. Deprivation-related inequalities were present for all oral cancer outcomes with a steeper rise at the more deprived end of the deprivation spectrum. Deprivation predicted oral cancer even after accounting for other risk factors.

### 1. Introduction

Oral cancer has been linked to lower socioeconomic status in both high income (HICs) and lower middle income countries (LMICs) [1] with those coming from poorer backgrounds being at greater risk [2]. Socioeconomic inequalities in oral cancer also exist between countries, for example countries ranked lower in the 'Human Development Index' in Latin America have also shown higher rates of oral cancer incidence and mortality [3]. UK studies have linked deprivation to various types of head and neck cancer [4,5] and oral cancer in particular [6]. Caution

must be exercised in the interpretation of these studies as they were conducted at different scales and the results may be influenced by ecological fallacies such as the modifiable areal unit problem [7].

The shape of socioeconomic inequalities in oral cancer is complex because of the associated risk factors. Around half of oral cavity cancers and 85–90 % of nasopharyngeal and pharyngeal cancers are attributable to population risk factors [8] and oral cancer is strongly linked to tobacco and alcohol [9], lifestyle risk factors which are associated with deprivation. On the other hand, cancer of the oropharynx and possibly parts of the oral cavity has been associated with Human Papilloma Virus

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(HPV) [10], a risk factor which is associated with higher socioeconomic status because of its links with sexual contacts and having multiple sexual partners [11,12]. The shape of socioeconomic inequality in oral cancer is, therefore, influenced by the contribution of opposing risk factors. In addition, inequality in early diagnosis of oral cancer contributes to shaping inequalities in oral cancer mortality [13,14].

In England, the incidence of oral cancer has been increasing since 1990 [5,15,16]. It is speculated that migration from the Indian sub-continent may have contributed to this trend [15], areas where the incidence of oral cavity cancer is higher [17]. In London between 2006 and 2010, for example, women from Pakistani, Bangladeshi and Indian ethnic groups had a significantly higher incidence of oral cancer compared to those from White ethnic groups [5]. This increase has been attributed to specific behaviours among South Asian ethnicities such as betel chewing and use of chewing tobacco [18]. A previous analyses of England data for oral cavity cancer has identified deprivation-linked inequality in survival, though survival overall was improving [19]. Recently published statistics for England for the period 2012–2016 [16] have highlighted significant geographic variation in cancers of the lip, oral cavity and pharynx, an almost doubling of incidence across income deprivation categories and around half of cancers presenting at an advanced (IV) stage, which affects prognosis.

Ecological studies of oral cancer have contributed to our understanding of head and neck cancers, including oral and oropharyngeal cancer, and their relationship with area-level deprivation, ethnicity, smoking and alcohol consumption [5,20–22]. There is, however, some variation in terms used by different studies and the specific sites included, which can make it difficult to compare studies. This ecological study used the same grouping of sites as the 2020 Public Health England report [16] and is an investigation into area-level deprivation and oral cancer outcomes in England over the period 2012–2016. Whilst anatomically related, these groupings included cancers of different aetiologies (ultraviolet radiation for cancers of the outer lip, tobacco and alcohol for cancers of the inner lip, oral cavity and pharynx, Human Papilloma Virus for cancers of the oropharynx and pharynx and radiation for cancers of the major salivary glands) and excluded bone cancers of the skull, face and mandible. The three main objectives of this study were: (a) to examine the pattern and magnitude of inequality, (b) to explore the shape of the relationship between deprivation ranking and oral cancer and (c) to investigate whether deprivation was an independent indicator of oral cancer outcomes accounting for ethnicity, smoking rate and alcohol consumption.

## 2. Material and methods

### 2.1. Data

Data for this national ecological study were obtained from the Public Health England National Cancer Registration and Analysis Service (NCRAS) [23]. These data are collected by the National Health Service as part of their care and support of patients and collated, maintained and quality assured by NCRAS. This study had four outcomes based on International Classification of Diseases (ICD) version 10: standardised incidence and mortality rates for cancers of the lip and oral cavity (C00–C06) and lip, oral cavity and pharynx (C00–C14). These were reported for lower tier and unitary local authorities in England, being the basic unit of local government.

Area-level deprivation was estimated by the Index of Multiple Deprivation (IMD) 2015. The IMD 2015 combines domains such as income deprivation, employment and education to estimate overall deprivation for small areas in England known as lower-layer super output areas (LSOA). In 2015, there were 32,844 LSOAs each containing 672 households on average. Local authorities were ranked according to their average IMD 2015 score [24].

Percentage of Asian ethnicity (Pakistani, Indian, and Bangladeshi) in each local authority was retrieved from the 2011 UK census [25].

Smoking was indicated by the prevalence of smoking among adults aged 18 and older in each local authority in 2015 [26]. Alcohol consumption was indicated by alcohol-related mortality rate in 2018 [27].

Standardised incidence rates for cancers of the lip and oral cavity (C00–C06) and cancers of the lip, oral cavity and pharynx (C00–C14) were reported for 324 out of 326 lower-tier English local authorities, data for two having been included in those for neighbouring authorities because of small numbers.

### 2.2. Data analysis

Standardised incidence rate ratios (IRR) and standardised mortality rate ratios (MRR) were calculated using the direct method by age and sex according to the 2013 European Standard Population. To examine the relationship between deprivation and oral cancer, standardised IRR and standardised MRR were reported for each deprivation quintile. These indicate the number of times the rate for each category is greater than that of the reference group. In our study, for example, an IRR or MRR value of 1.8 for the most deprived group of local authorities would suggest that the incidence or mortality rate of cancer is 1.8 times greater than that of the least deprived category. We also used relative index of inequality (RII) to report inequalities. The RII is a regression-based summary measure of inequality [28] and is interpreted as the relative difference between the hypothetical least and most deprived local authorities taking into account the distribution of the disease outcome across all geographical units rather than extreme ends of deprivation. Further, it accounts for the population size of each geographical unit (lower-tier English local authorities in this study). Data were analysed using Stata. We set out to present P-values as continuous estimates instead of defining  $\alpha$  cutoff for statistical significance.

To explore the shape of the relationship between deprivation and oral cancer outcomes, we tested the null hypothesis of linearity against alternative regression functions and selected the best fitting model. In doing so, we used fractional polynomial regression and the algorithm proposed by Royston and Sauerbrei [29] to evaluate whether the effect of a continuous variable (i.e. deprivation ranking in this study) on the outcome (i.e. oral cancer) is better modelled by a nonlinear fractional polynomial (FP) function. FPs are of the form:

$$Y = B_0 + B_1 X^{p_1} + B_2 X^{p_2} + \dots$$

where  $p_1, p_2, \dots$  are selected from default set of powers  $\{-2, -1, -0.5, 0, 0.5, 1, 2, \text{ and } 3\}$  with 0 representing logarithm of variable. In this formula,  $Y$  represents the cancer outcome (e.g. standardised incidence rates for cancer of the lip and oral cavity),  $B_0$  is the intercept, and  $X$  represents deprivation ranking of local authority. The  $B_1$  and  $B_2$  coefficients capture the effect of first and second orders for deprivation ranking, respectively. Conventionally, fractional polynomial models that involve two terms (i.e. first and second orders) are assumed to be adequate for identifying the best fit [30]. Therefore, we fitted 44 models for each cancer outcome with the combinations of powers fitted, out of those we reported the statistical estimates for the linear model and first order ( $m = 1$ ) and best fitting second order models ( $m = 2$ ) for the above-mentioned default set of powers:

$$\text{Cancer} = B_0 + B_1 \text{Deprivation}^{p_1} + B_2 \text{Deprivation}^{p_2}$$

We selected the best fit model between selected models based on the algorithm suggested by Royston and Altman [31] which estimates the deviance where deviance is defined as twice the negative log likelihood. In addition to deviance, we reported the estimates of the residual standard errors and the p-values for the partial F test comparing models' deviance. We used the STATA 'fp' command and the proposed selection model to produce and compare polynomial fractional models to choose the simplest as well as best fitting model [32]. As such, we initially compared the best fitting second order model ( $m_2$ ) with the linear

model. If this did not provide a statistically better fit, the linear model was selected. Otherwise, the best fitting second order model (m2) was compared with the best fitting first-order model (m1). The best fitting second order model (m2) was preferred to first order model (m1) only if it provided a statistically better fit, otherwise, the first order model (m1) was selected. The shape of the relationship between deprivation and oral cancer was also visualised for the linear and best fitting fractional polynomial model. There was no evidence of interaction between deprivation ranking and the covariates smoking, alcohol and ethnicity therefore interaction terms were not added to models.

### 3. Results

The first objective of this study was to examine the pattern and magnitude of inequality. Data analyses for this objective are shown in Table 1, which presents the standardised incidence rate ratios (IRRs) and standardised mortality rates ratio (MRRs) for cancer outcomes across deprivation categories. Overall, the IRRs and MRRs were consistently greater for more deprived categories. For example, the IRRs of lip and oral cavity cancer (C00-C06) in the most deprived local authorities in England were 1.26 times greater than the least deprived group. Table 1 also shows the RIIs for each cancer outcome. Overall, the values of RIIs were significant for all four cancer outcomes, confirming the greater incidence and mortality in more deprived local authorities, taking into account the population size of English areas. For example, the RII for mortality of C00-C14 implies that risk of mortality due to cancer of the lip, oral cavity and pharynx in the most deprived local authorities was nearly twice that of the least deprived (RII = 1.95, 95 % CI = 1.79, 2.12;  $p < 0.001$ ).

The second objective of this study was to explore the shape of the relationship between deprivation ranking and oral cancer outcomes for which we used fractional polynomial models and the results are shown in Table 2. Values of 'deviance difference' for linear and first order model ( $m = 1$ ) represent the extent to which second order model ( $m = 2$ ) is, comparatively, a better fit. In other words, the higher values of deviance difference indicate a better fitness of second order model compared to linear and first order models. The regression model for standardised incidence ratio for cancers of the lip and oral cavity (C00-C06), for example, suggests that the best fitting second order model (m2) provided a better fit than that of the linear model (deviance difference = 13.53,  $p = 0.004$ ) though, it did not provide a significantly better fit than that of the best fitting first order (m1) model (deviance difference = 4.601,  $p = 0.104$ ). Therefore, the first order (m1) model which had a power 3 for deprivation (cubic term) provided a better fit among 44 models. Similarly, the best fitting first order models with the cubic term for deprivation were the most suitable models explaining the relationship between deprivation ranking of English local authorities and two other oral cancer outcomes: standardised incidence rates (C00-C06) and mortality rates (C00-C14). The only exception was mortality rate for cancer of the lip and oral cavity (C00-C06) for which the best fitting model had a power 2 (quadratic term) for deprivation. Both quadratic and cubic functions imply the varying effect of deprivation on cancer incidence and mortality such that the impact of deprivation was most

pronounced in the most deprived local authorities. The best fitting model and linear line for each outcome are shown in Figs. 1 and 2, showing a steeper rise in incidence and mortality rates at the more deprived end of the range.

The third objective of this study was to examine whether deprivation independently predicts oral cancer, accounting for the known risk factors for oral cancer: Asian ethnicity, smoking prevalence and alcohol consumption. Informed by our previous analyses, we fitted regression models with quadratic and cubic functions for deprivation accordingly and added Asian ethnicity, smoking prevalence and the proxy variable for alcohol consumption to the model. Table 3 reports the findings of unadjusted and adjusted multivariable regression models. In unadjusted models, deprivation was significantly related to oral cancer outcomes, explaining between 21%–42% of variations in incidence and mortality of oral cancer as indicated by the values of adjusted R-squared. Deprivation remained a significant predictor of incidence and mortality from oral cancer in adjusted models after controlling for the effect of Asian ethnicity, smoking prevalence and the proxy variable for alcohol consumption. Interestingly, addition of these covariates to the models did not substantially increase the values of adjusted R-squared (less than 4% across the models). In all adjusted models, Asian ethnicity and alcohol consumption were positively associated with incidence and mortality rates of oral cancer. At bivariate level, smoking was significantly linked to increased incidence and mortality rates from oral cancer outcomes (data not shown) though it was not a significant predictor in the adjusted models (model 2). Alcohol consumption was, however, directly related to all oral cancer outcomes except for mortality rates for C00-C14 (Coefficient = 0.01; 95 % CI = -0.01, 0.03).

### 4. Discussion

This study provides an updated understanding of oral cancer in England since the 2011 profile published by the Oxford Cancer Intelligence Unit [15]. We found that deprivation at area level was strongly associated with incidence and mortality for both cancers of the lip and oral cavity and cancers of the lip, oral cavity and pharynx, suggesting that risk factors associated with deprivation continue to predominate. A recent study also reported socioeconomic inequalities in oral cancer in London [5] though this investigation was limited to bivariate analyses due to low numbers. Our study is the first, to our knowledge, to explore the shape of socioeconomic inequalities in oral cancer at neighbourhood level. We found that the shape of relationship between deprivation ranking and oral cancer incidence and mortality was not linear and appeared stronger with increasing deprivation. A 2014 Canadian study also reported that an increase in the incidence of oral cancers was not proportionate between different deprivation quintiles [33]. Our study not only confirms the findings of the Canadian study, but also explored and depicted the shape of such inequalities. Finally, we found that deprivation was a significant risk factor after adjusting for alcohol, smoking and Asian ethnicity. Our study used groupings of cancer sites that have been used elsewhere but which reflect a range of aetiologies which makes interpretation challenging. It is arguable that different grouping of cancers based either on an oral screening premise (for

**Table 1**

Deprivation related inequalities in the standardised incidence and mortality rates for cancers of the lip and oral cavity (C00-C06) and lip, oral cavity and pharynx (C00-C14) between local authorities in England, 2012-2016.

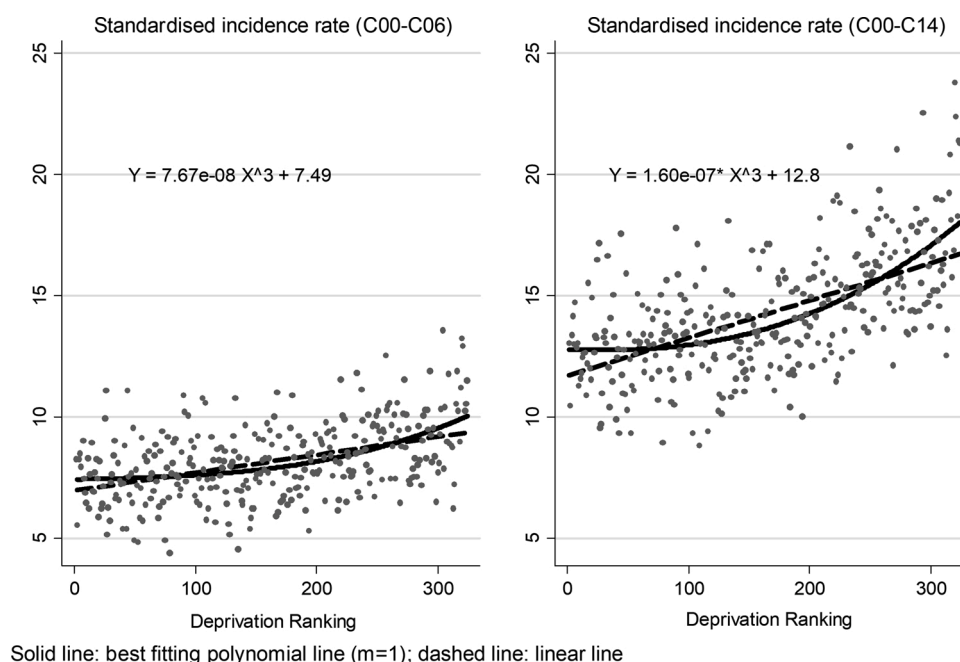
	Standardised incidence rate ratio (C00-C06)	Standardised incidence rate ratio (C00-C14)	Standardised mortality rate ratio (C00-C06)	Standardised mortality rate ratio (C00-C14)
Least deprived local authorities	Ref	Ref	Ref	Ref
2nd quintile	1.06 (0.93, 1.20)	1.02 (0.93, 1.13)	1.05 (0.81, 1.36)	1.01 (0.84, 1.21)
3rd quintile	1.06 (0.93, 1.20)	1.06 (0.96, 1.17)	1.22 (0.95, 1.57)	1.17 (0.98, 1.39)
4th quintile	1.19 (1.06, 1.35)	1.21 (1.10, 1.33)	1.37 (1.07, 1.75)	1.37 (1.15, 1.62)
Most deprived local authorities	1.26 (1.12, 1.42)	1.31 (1.19, 1.43)	1.56 (1.23, 1.98)	1.58 (1.34, 1.86)
Relative Index of Inequality (RII)	<b>1.38 (1.29, 1.47)</b>	<b>1.47 (1.39, 1.55)</b>	<b>1.86 (1.66, 2.08)</b>	<b>1.95 (1.79, 2.12)</b>

**Bolded estimates:** significant values of RII at confidence level of 95 % are bolded ( $p < 0.001$ ).

**Table 2**

Comparison of linear and non-linear fractional polynomial regression models for the relationship between deprivation and oral cancer outcomes.

		df <sup>a</sup>	Deviance	Res. SD	Deviance difference	P values	Powers
Standardised incidence ratio (C00-C06)	linear	1	1149.20	1.43	13.55	0.004	1
	m = 1	2	1140.27	1.41	4.62	0.103	3
	m = 2	4	1135.65	1.40	0.00	–	–2, 3
Standardised incidence ratio (C00-C14)	linear	1	1382.60	2.05	22.51	< 0.001	1
	m = 1	2	1361.06	1.98	0.97	0.621	3
	m = 2	4	1360.09	1.98	0.00	–	2, 2
Standardised mortality ratio (C00-C06)	linear	1	630.70	0.64	9.48	0.025	1
	m = 1	2	622.31	0.63	1.08	0.588	2
	m = 2	4	621.23	0.63	0.00	–	0.5, 3
Standardised mortality ratio (C00-C14)	linear	1	917.26	1.00	27.13	< 0.001	1
	m = 1	2	891.16	0.96	1.03	0.602	3
	m = 2	4	890.12	0.96	0.00	–	1, 3

<sup>a</sup> df: degree of freedom.**Fig. 1.** Standardised incidence rate and deprivation ranking of English local authorities.

example excluding some pharyngeal sites but including facial skeleton bone tumours) or a more defined aetiology (for example excluding external lip and salivary tumours and attempting to separate out sites more likely to be HPV-related) should be the focus of future studies.

Greater incidence and mortality rates in more deprived areas could be explained in a number of ways and it has been argued that this could represent multiple factors such as nutrition and access to healthcare acting in synergy with tobacco and alcohol consumption [34]. In our study the magnitude of inequality for mortality indices was greater than for incidence rates, with a doubling of mortality for cancer of the lip, oral cavity and pharynx between the most and least deprived local authorities. The apparent double effect of deprivation in our study possibly reflects a lower likelihood of earlier diagnosis and treatment among deprived communities who are already at greater risk of disease. This has significant implications for policy development where recommendations on strategies for reducing morbidity and mortality from these cancers should address both risk factors and uptake of diagnostic and treatment services [35]. There is no national screening programme for cancers of the lip, oral cavity or pharynx in the UK, though this is under review [36] and identification of pre-cancer and early cancer is dependent on dental attendance for opportunistic screening and the effectiveness of the examinations undertaken by dentists. The UK body NICE recommends that adults should have oral health reviews at least every 2

years [37] or more frequently if the risk of disease is higher. In the 2009 national adult dental health survey 22% of dentate adults from the most deprived group of respondents in England, Wales and Northern Ireland [38] said their last visit to the dentist was more than two years previously and 30% said that their normal dental attendance interval was greater than two years. A recent study in England [39] has suggested that a high proportion of people from more deprived communities are referred for oral cancer diagnosis by their doctor rather than a dentist, which suggests a symptom-led pathway. Strategies to reduce mortality should, therefore, include ways of encouraging those most at risk to attend a dental practice for regular check-ups to enable opportunistic screening for pre-symptomatic lesions.

Interestingly, deprivation was an independent risk factor for oral cancer in our study, even accounting for established behavioural risk factors and Asian ethnicity. Unlike alcohol consumption and Asian ethnicity, which were associated with an increased risk of oral cancer outcomes, smoking rate was not an independent predictor in the adjusted models at local authority level. This may reflect our selection of tobacco indicator in addition to other limitations of this study. We need to acknowledge, however, that our analyses were based on aggregate data; inferring individual risk from population-level associations raises the ecological fallacy and caution is needed when trying to compare the findings of this study with those using individual level data.



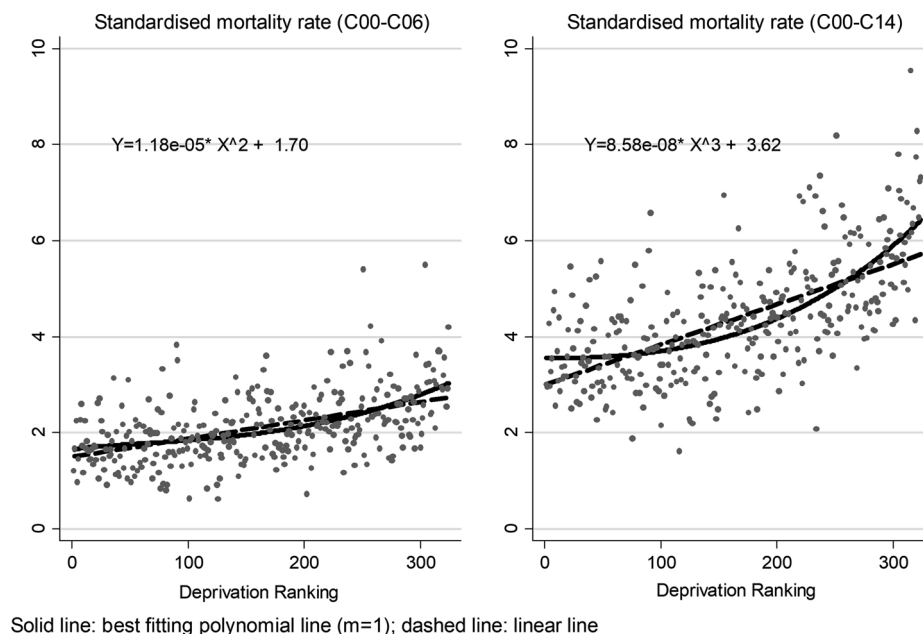


Fig. 2. Standardised mortality rate and deprivation ranking of English local authorities.

Table 3

Unadjusted and multivariable regression models for the association between deprivation ranking of English local authorities and oral cancer outcomes.

Model 1	Standardised incidence rate [95 % CI] (C00-C06)	P values	Standardised incidence rate [95 % CI] (C00-C14)	P values	Standardised mortality rate [95 % CI] (C00-C06)	P values	Standardised mortality rate [95 % CI] (C00-C14)	P values
Deprivation Ranking <sup>±</sup>	7.67e-08 [6.08e-08, 9.26e-08]	< 0.001	1.60E-07 [1.37E-07, 1.82E-07]	< 0.001	1.18E-05 [9.63E-06, 1.40E-05]	< 0.001	8.58e-08 [7.50e-08, 9.66e-08]	< 0.001
Constant	7.50 [7.29, 7.70]	< 0.001	12.84 [12.55, 13.13]	< 0.001	1.70 [1.59, 1.80]	< 0.001	3.62 [3.48, 3.76]	< 0.001
N	324		324		324		324	
Adjusted R-squared	0.216		0.378		0.225		0.428	
Model 2	Standardised incidence rate [95 % CI] (C00-C06)		Standardised incidence rate [95 % CI] (C00-C14)		Standardised mortality rate [95 % CI] (C00-C06)		Standardised mortality rate [95 % CI] (C00-C14)	
Deprivation Ranking <sup>±</sup>	3.65e-08 [1.04e-08, 6.26e-08]	0.006	1.14E-07 [7.72e-08, 1.51E-07]	< 0.001	7.92E-06 [4.08E-06, 1.18E-05]	< 0.001	6.69e-08 [4.89e-08, 8.49e-08]	< 0.001
Asian ethnicity	0.05 [0.02, 0.07]	< 0.001	0.04 [0.01, 0.07]	0.029	0.02 [0.01, 0.03]	< 0.001	0.03 [0.01, 0.04]	0.002
Smoking	-0.017 [-0.07, 0.03]	0.497	-0.04 [-0.11, 0.04]	0.318	0.01 [-0.02, 0.03]	0.849	0.01 [-0.02, 0.05]	0.462
Alcohol consumption	0.05 [0.02, 0.07]	< 0.001	0.07 [0.03, 0.10]	< 0.001	0.01 [0.001, 0.02]	0.044	0.01 [-0.01, 0.03]	0.090
Constant	5.61 [4.46, 6.76]	< 0.001	10.43 [8.81, 12.05]	< 0.001	1.16 [0.63, 1.68]	< 0.001	2.76 [1.97, 3.55]	< 0.001
N <sup>∞</sup>	310		310		310		310	
Adjusted R-squared	0.264		0.408		0.285		0.446	

<sup>±</sup> Deprivation was fitted with cubic function for cancer outcomes except for mortality rate (C00-C06) where it was entered as quadratic function.

<sup>∞</sup> Adjusted models were analysed using data from 310 out of 324 local authorities due to missing data on alcohol consumption in 14 local authorities.

Model 1: Unadjusted estimates for the effect of deprivation ranking on oral cancer outcomes.

Model 2: adjusted estimates for the effect of deprivation on oral cancer outcomes accounting for the effect of smoking, alcohol consumption and Asian ethnicity.

Furthermore, the prevalence of smoking is a crude indicator and it is known that intensity and duration of smoking are better predictors [41]. Nevertheless, several studies [42,43] have shown a stronger association between tobacco and oral cavity cancer compared with alcohol alone and, most significantly, a far greater risk from alcohol and tobacco in combination. Upstream public health interventions to reduce use of tobacco and alcohol, such as measures to reduce availability and affordability, are valuable to reduce the incidence of oral cancer in addition to the other impacts on oral and general health.

While the fractional polynomial modelling allowed us to reveal the

non-linear shape of inequalities in oral cancer, other flexible methods such as generalised additive models and generalized additive mixed models could also have been utilised. Given the effect of geographical variation in the relationship between deprivation and oral cancer incidence [44], it is likely that the spatial clustering have affected the model fits in our study. Further, limitations attached to the ecological study design apply to this research, for example ethnicity may have changed in some areas since 2011. For the same reason, we did not account for the effect of individual-level indicators of socioeconomic status, though previous studies have shown that area-level deprivation is associated

with higher incidence of head and neck cancer [4,40] after taking into account the individual indicators of socioeconomic status. We did not investigate the inequality trend over time, whether deprivation-related inequalities between local authorities are narrowing or widening between 2012 and 2016, nor did we investigate changes in ethnicity over time. Since there are some signs of increasing inequalities in oral health [45] and cancer [46] in the past decade in England, it would be important to explore whether this pattern is replicated for oral cancer.

## 5. Conclusions

We have identified significant deprivation-related inequality in both the incidence and mortality for cancers of the lip and oral cavity and lip, oral cavity and pharynx in England, which is more pronounced in the most deprived local authorities. The inequality was more pronounced for mortality, suggesting a dual effect. Policy to reduce inequality in mortality from oral cancer should address service factors as well as risk factors.

## Authorship contribution statement

V.R. designed the secondary data analysis and, with A.J.M, led on drafting the manuscript. C.D, K.J., R.G., J.M.J., G.D., D.W., M.D., S.W. and Y.D. contributed to primary study design, data acquisition and interpretation, manuscript preparation and manuscript editing.

## Data statement

The oral cancer data used in this research have been published in summary tables of the 2020 Public Health England report 'Oral cancer in England' (1). To comply with suppression rules, data for local authorities with fewer than 10 cases were removed from the tables. For these analyses, however, we used the non-suppressed data for all local authorities which may not be published in accordance with the PHE guidance for maintaining confidentiality. The data for tobacco and alcohol are contained in the published local authority health profiles (2–3). Percentage of Asian ethnicity (Pakistani, Indian, and Bangladeshi) in each local authority was retrieved from the 2011 UK census.

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## Ethics approval

This was a secondary analyses of national data. Ethical approval was not applicable.

## Consent for publication

Not applicable.

## Data availability

The oral cancer data used in this research have been published in summary tables of the 2020 Public Health England report 'Oral cancer in England'. To comply with suppression rules, data for local authorities with fewer than 10 cases were removed from the tables. For these analyses, however, we used the non-suppressed data for all local authorities which may not be published in accordance with the PHE guidance for maintaining confidentiality.

## Declaration of Competing Interest

The authors report no declarations of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.canep.2020.101840>.

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